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J Main and
G I Sangster

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J Main and G I Sangster

Marine Laboratory Aberdeen

Introduction

One of the concerns of gear technologists and marine biologists involved in problems of fish capture is to understand and improve the efficiency of fishing gear. Numerous methods for tackling this problem have been developed and operated with varying success using remote apparatus attached to the gear, for example underwater measuring instruments on the gear (Nicholls, 1964), echo sounders (Okonski, 1967), remote photography (Craig and Priestley, 1963), submersibles (Anon, 1965), and remote television (Sand, 1957; Livingstone, 1959). The use of diving techniques to observe model nets was reported by Dickson (1961) and Schärfe (1963), but more recent work by Hemmings (1967a, 1967b) and High (1967) underlined the value of direct observation methods in research involving full scale fishing gears.

At the Marine Laboratory, Aberdeen, research on nets has increased recently, and diving techniques have been developed to investigate the performance of full-sized trawls. Research work on trawls had been limited to measurements of net geometry and warp tension made by remote instrumentation, and it was felt that diving methods might extend these observations and allow further assessment of the factors influencing net geometry and fishing performance. The observations made by the divers could easily be co-ordinated with those measurements recorded by the instruments, and direct observation soon became a routine additional check on the performance of trawls. This paper reviews and evaluates various diving techniques developed by the Aberdeen Marine Laboratory diving team in the study of fishing gears.

Materials and Methods

Fishing and Diving

Most of the work was normally conducted from research vessels operating on a test area off Lossiemouth (57^{o} 41'N 03^{o} 03'W), but some experiments have been carried out from commercial boats (Sangster and Hemmings, 1971). During the past eight years more than three thousand dives, totalling 1,600 hours, have been made by the team involved in gear research.

When a bottom trawl was observed, it was shot away and towed into the test area. Towing speeds ranged from 2.5 to 3.5 knots (1.28 to 1.80 m s^{-1}), depending on the particular experiment or direction of tidal flow. The divers, given a signal from the bridge, entered the water from an inflatable boat and descended the trawl warps to the net on the sea bed. Depending on the pre-determined task, the divers would either observe and film the gear as it passed by them or would hang onto the netting and be towed along with the gear. A minimum of two, but no more than three, divers were employed on each dive. Each diver was briefed regarding safety and emergency procedures before entering the water. They were instructed to watch closely for each other, meet at the headline of the net on completion of their tasks, and return together to the surface. Radio communication was maintained between the inflatable support boat and the fishing vessel. The procedures used whilst diving on seine nets were described by Parrish, Hemmings, Chapman, Main and Lythgoe (1964).

All diving was conducted within the rules and regulations for scientific diving in the Marine Laboratory, which pay careful attention to the Royal Naval Physiological Laboratory's (Anon, 1972) air decompression tables and to the Underwater Association Code of Practice for Scientific Diving (Flemming and Miles, 1974). Only the fittest and most experienced divers, well versed in fishing procedures and capable of finding their way around nets, took part in these experiments.

Bad weather is the major limiting factor in fishing gear diving, although in sheltered areas it has been possible to operate in sea state 4 and up to wind Force 6 (Beaufort). Diving at night or in semi-darkness was not considered safe for this type of work.

Equipment

6 mm thick neoprene rubber wet suits were generally worn, but for more prolonged diving in winter the 'Unisuit' (manufactured by Poseidon Diving Equipment, Göteborg, Sweden), a dry, manually inflatable, foam neoprene rubber suit worn over wool/nylon underwear, was introduced. The use of the 'Unisuit' overcame the problem of cold by insulating the body against temperatures ranging from 3 to 5° C (Bevan, 1973), bearing in mind that towing at speeds up to 3.5 knots (1.80 m s^{-1}) in northern waters can quickly chill a diver, thus reducing his effectiveness and increasing the probability of 'bends' (Hempleman, 1967).

The standard twin-hose demand valve was modified by replacing the softer hoses with a more rigid type (Royal Navy - heavy duty pattern) to minimise the breathing problem caused by tubes collapsing owing to water flow when towing at speeds in excess of 2.5 knots (1.28 m s^{-1}). The normal mouth piece was replaced with a mouth box manufactured by Nautilus Bioengionics Co., California, USA, to permit clear voice recording and to reduce any strain on the diver's jaw. Single hose equipment was not considered suitable, owing to the presence of air bubbles around the face mask and to the high drag on the mouth box.

Depth gauges were of the standard 'SOS' Professional Helium type, easily readable to within 0.25 metre. All gauges were regularly calibrated in a compression chamber.

Voice Recording and Photography

A small Sanyo M48M cassette tape recorder was housed in a watertight pressure case (Plate I) with a connecting cable to a bone conduction microphone worn under the divers hood. The apparatus, strapped to an aqualung, was carried by a diver whenever detailed information was to be collected.

The main aim of each dive was to gain as much information as possible in the short 'no decompression' time available. It was found that the time was best used if, before entering the water, each diver was asked to concentrate single-mindedly on one set task. The results from a successful dive tended to be in one of two forms, either an extensive tape recording of observations supported by a few photographs, or a long series of good quality photographs with limited additional information on tape. Transcription of the tape recordings was carried out as soon as possible after each dive, so that ambiguities could be discussed or eliminated and supplementary information added whilst still fresh in the diver's memory. The Appendix shows the transcript of an actual commentary, demonstrating the quantity of information a diver is capable of producing in a relatively short dive.

Some of the earlier photography of the nets was done using Nikonos underwater cameras fitted with 35 mm lenses. However the 28 mm Nikonos lens greatly enhanced the results, since the wider angle of acceptance produced better coverage of the net. A Telford 16 mm camera (60 m load) was used

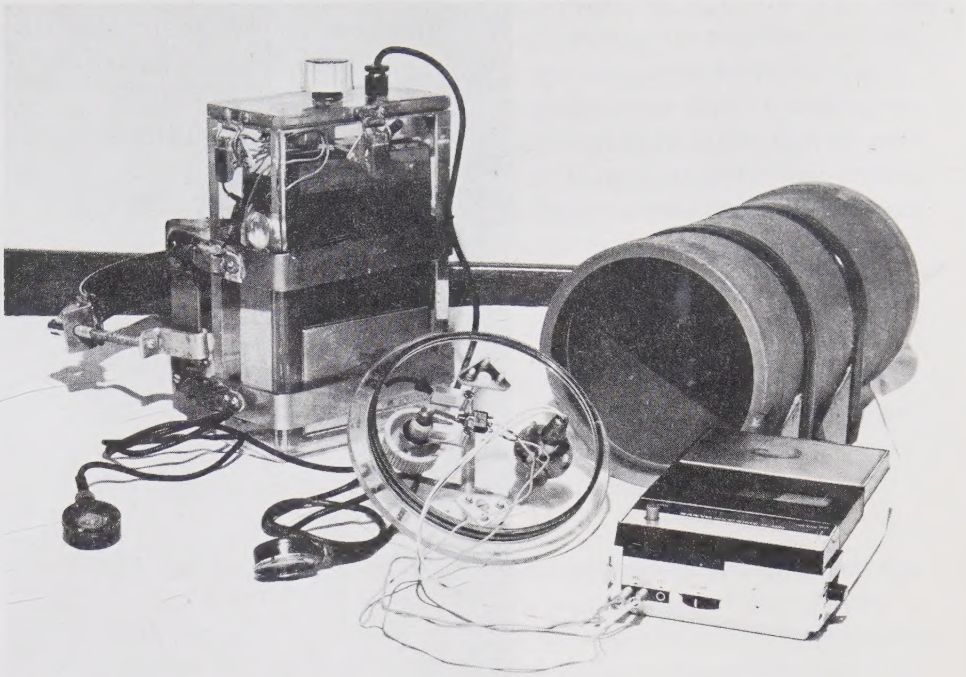

Plate I Two types of underwater tape-recorder housing in use. That on the left is made of 9 mm thick clear perspex, that on the right from 9.5 mm thick plastic tubing with a clear perspex lid.

for most of the cine work, although a Beaulieu automatic 16 mm camera in a "Hugyphot" housing (30 m a load) was included for some aspects of the filming, especially the colour sequences. Conventional clapperboard techniques were used to label film sequences.

Poor contrast of various parts of the net against the water background gave some initial problems. To alleviate this, it was suggested that, unless it interfered with a fishing procedure or experiment, it would be advantageous to use nets coloured to give maximum contrast on film, ie white against a dark background, or a darker shade when working on a light sandy bottom (Hemmings, 1972). Recent experiments have produced photographic evidence which underlined the necessity for nets tailored in twines of contrasting colours whilst operating in turbid waters. Plates II and III demonstrate nets tailored with contrasting twines. The problem of low contrast was also reduced by experimenting with films, uprating speeds and modifying the development times.

Further improvements in observation were obtained, in both seine net and demersal trawl experiments, using the RCA Sitcon Television system, which allowed the recording of good quality pictures in low ambient light levels and low contrast in turbid water. A further advantage of television is that real time data can be superimposed on the video tape. The experience and increasing knowledge of gears in action already gained allowed the diving team to produce films on video tape after only a few trial runs on the nets. These provided an immediate surface display, enabling rapid assessment by gear experts of any defects in the nets and allowing modifications to be carried out after each haul (Main and Sangster, 1976; Wardle and Priestley, 1976).

Net Measurements

Divers had reported on many occasions that instruments attached to fishing gears to record various parameters were causing gross distortions, severely affecting gear shape and probably its fishing performance. It was therefore decided to limit instrumentation to the minimum and experiment with simple apparatus which the divers could operate. A critical measurement is

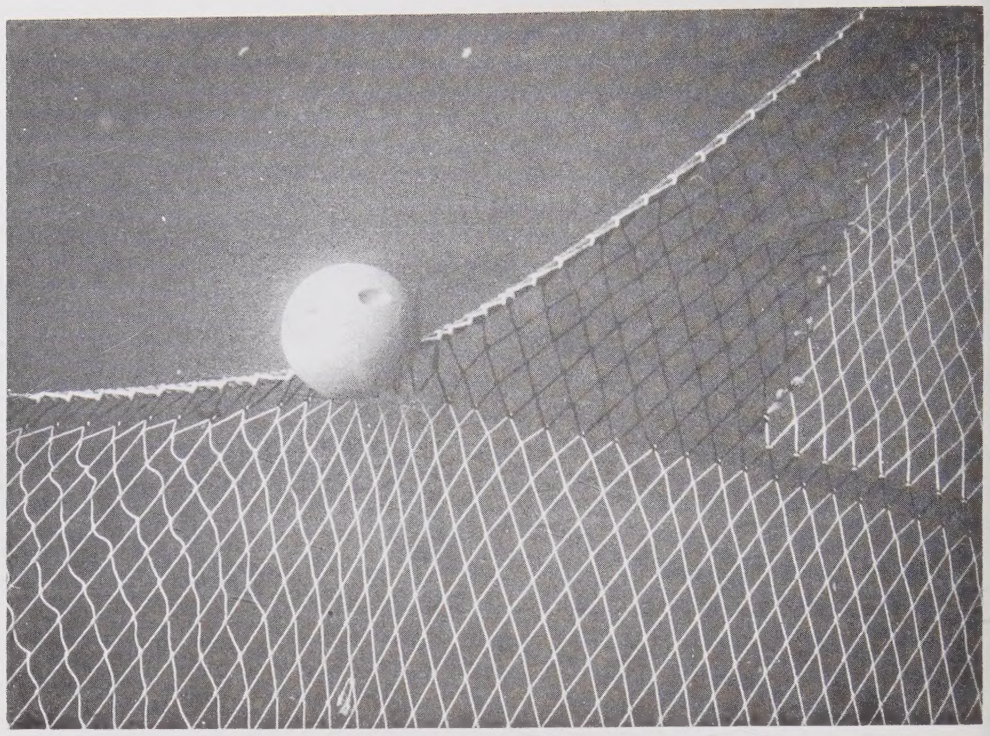

Plate II. Vertical view of headline gusset area of a bottom trawl demonstrating the contrast of different twines against the water background. Depth 26 m.

the spread or opening of the whole net. This was achieved by attaching 'courlene' strings, marked in metres and centimetres across critical points on the net whilst still on deck. During fishing it was found practicable for the divers to pull in the slack string and read off the spread measurement to the nearest five centimetres. The height of parts of the gear above the sea bed were measured by the diver reading his depth gauge to record the water depth at the bottom and at particular points on the gear. From the recorded readings the heights of different parts of the gear relative to the bottom were calculated to an accuracy of 0.25 m.

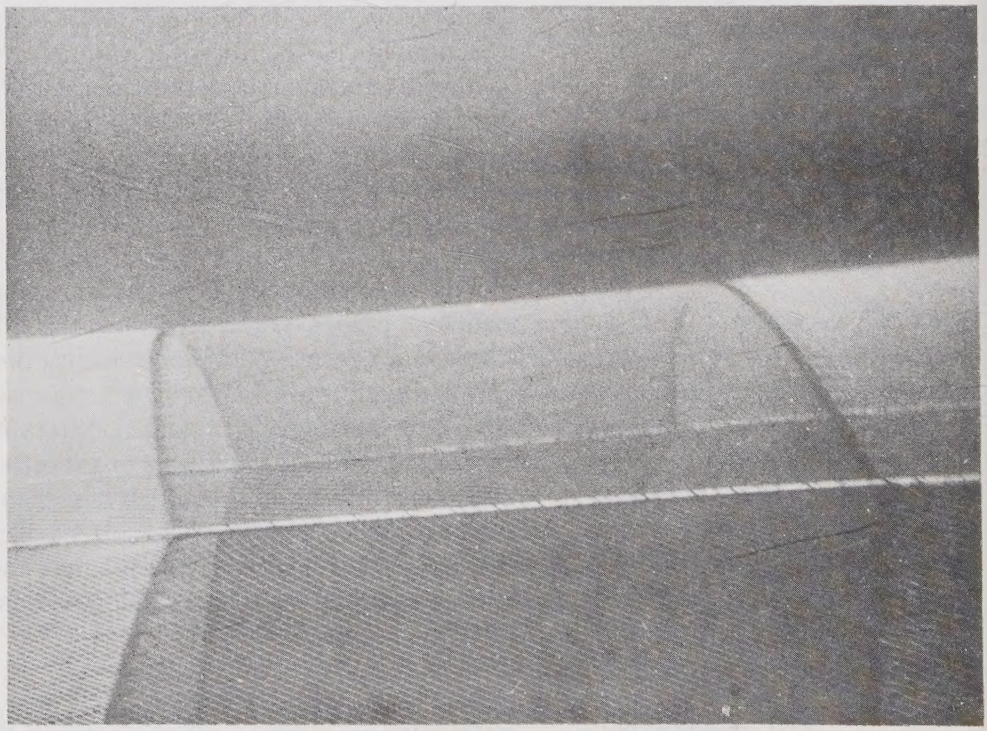

Plate III. Horizontal view of the funnel of a pelagic trawl showing panels tailored in contrasting twines. Depth 29 m.

A gauge was designed to measure sizes of individual meshes in the net. It was used to measure the degree of mesh opening in various parts of the net and the variation in mesh opening between adjacent net panels when fishing at different speeds. The net was marked off in squares, the diver recording the length of eight mesh openings per square. Care had to be taken that no part of the diver was in contact with the netting or causing strain on the meshes, which would introduce biased readings. The ideal method was to plane back from the wing-end or headline whilst hanging onto a fixed rope, such as a leach line. In addition detailed observations were made at any points of strain in the netting.

A marked pole or metre stick was used to record the height of the ground rig above the sea bed at different points along its length. The pulsing effect of the groundline due to the ship pitching in heavy swell was observed and the groundline rig lifting off the sea bed was recorded on cine film.

Otterboard Performance

Two divers descended the towing warp and photographed and observed the passing otterboard, one filming from the side and the other filming from directly above. This technique was repeated, varying the towing speed, length of warp and board attachment point, in order to gain knowledge relating to board stability and its angle of attack.

Otterboard and Trawl Turbulence

To understand the hydrodynamics of fishing gear it is essential to have information on the flow of water through or past the net and trawl door. Two dyes, Rhodamine B and Fluorescein, were used to observe the turbulence and flow patterns around otterboards and in the mouth of nets.

Otterboards

The dye, impregnated on tissue paper, was contained in a plastic tube, approximately 50 mm in diameter, 250 mm in length and capped at both ends. A 6 mm diameter hole was drilled in each cap and covered with waterproof tape, and the complete device was strapped firmly to the towing warp approximately one metre in front of the otterboard prior to shooting the gear. The tape was removed in the water by one diver while the other visually assessed and photographically recorded the flow patterns of the dye around the board.

Trawl Net

The water flow in and around the mouth of a net was observed by one diver dropping a small weighted metal canister of dye in the path of the net whilst his companion filmed horizontally, near ground level, deflections of the vertical dye column as it passed through the net.

Results

In the majority of hauls, two divers were able to record eleven basic heights and five critical spread measurements (Fig. 1), which were used to plot an accurate shape of the net under normal fishing conditions. Figure 2 shows some extra parameters recorded when required.

The measurement of net parameters by divers, using the methods described together with tape-recorded information on net behaviour, supplied valuable data leading to experimental development and modification of trawls (Corrigall, Galbraith and Wileman, 1975; Corrigall and Watson, 1977). The measurements of meshes and the manual tailoring of net panels were carried out on nets whilst towing at speed. Figure 3 shows the depth profiles of the top edge of an experimental pelagic trawl before and after tailoring by divers.

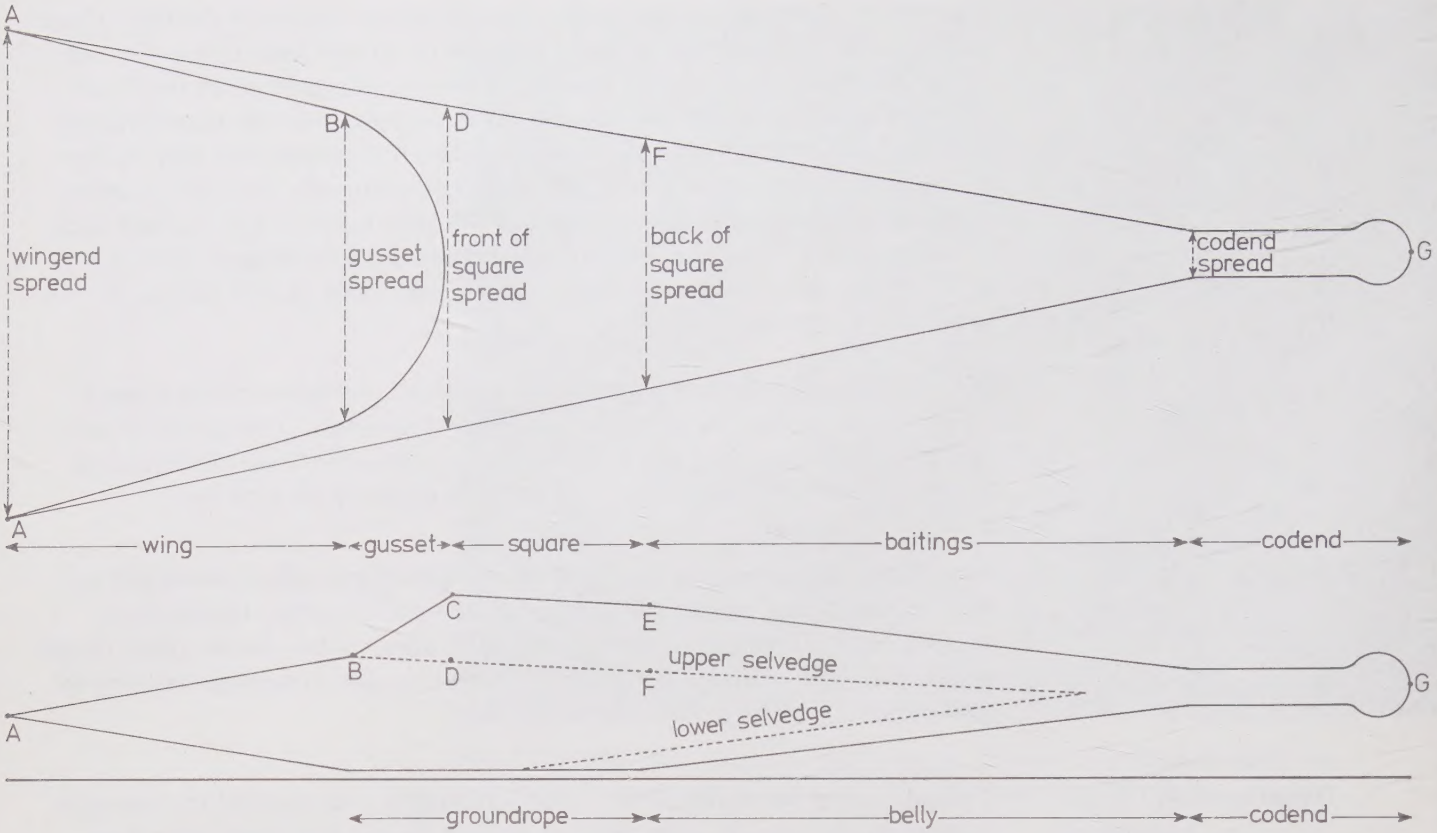

Figure 1. Positions of routine measurements taken by divers using depth gauges (lettered dots on top and side views) and marked strings (dashed lines). Scale 6.5 mm = 1 m.

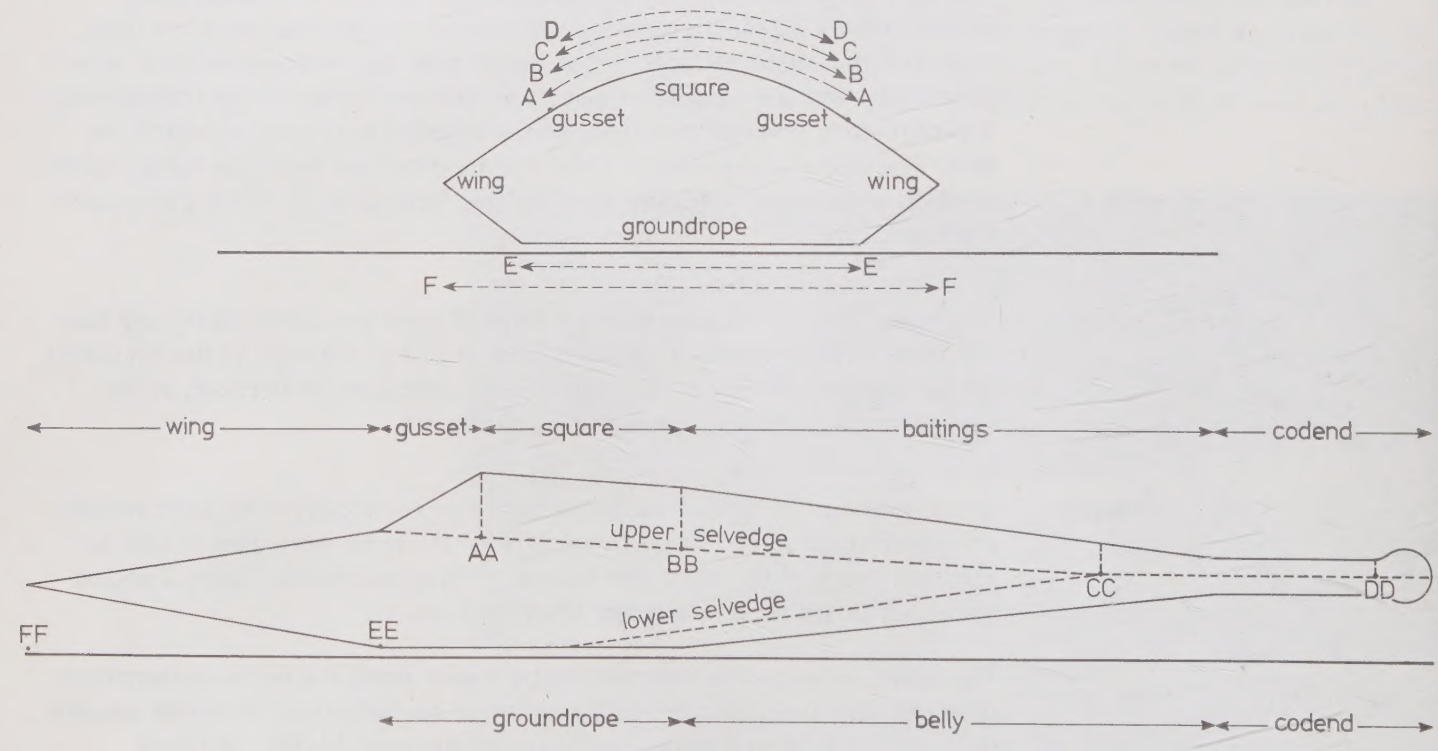

Figure 2. Secondary measurements taken by divers using marked strings only. AA - curved length at front of square; BB - curved length at back of square; CC - curved length at back of baitings; DD - curved length at the codend; EE - groundrope spread; FF - spread of warps, directly below the wing ends. Scale 6.5 mm = 1 m.

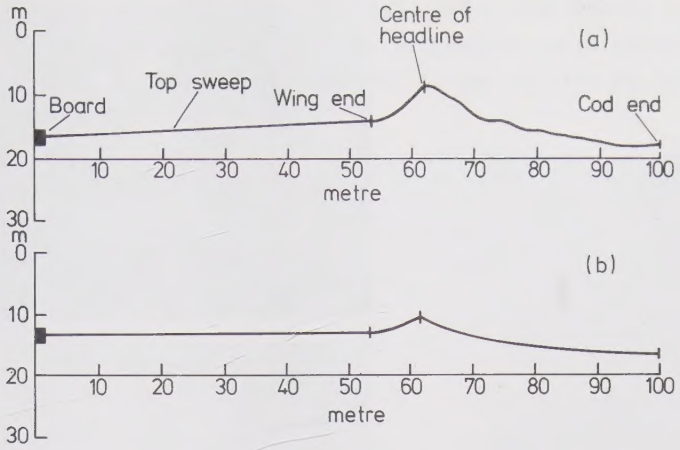

Figure 3. Two depth profiles of the top edge of a graded mesh pelagic net measured by divers swimming from the board to the codend, (a) before and (b) after tailoring.

The use of dye packs around seine-nets and trawls helped to describe the water flow around otterboards and net. The dye column was clearly seen to pass into the mouth of the net, remaining intact as far as the entrance to the cod-end, where it rapidly dispersed. This technique showed that a forward displacement of water occurred only in the area to the rear of the net, whereas previously it had been thought by some gear scientists that a wall of water might be pushed ahead of the net. Both dyes were filmed with success, but the reddish colour of Rhodamine B gave poor contrast. Fluorescein provided the best photographic results. Plates IV and V show examples from the dye experiments in progress around the net and otterboards.

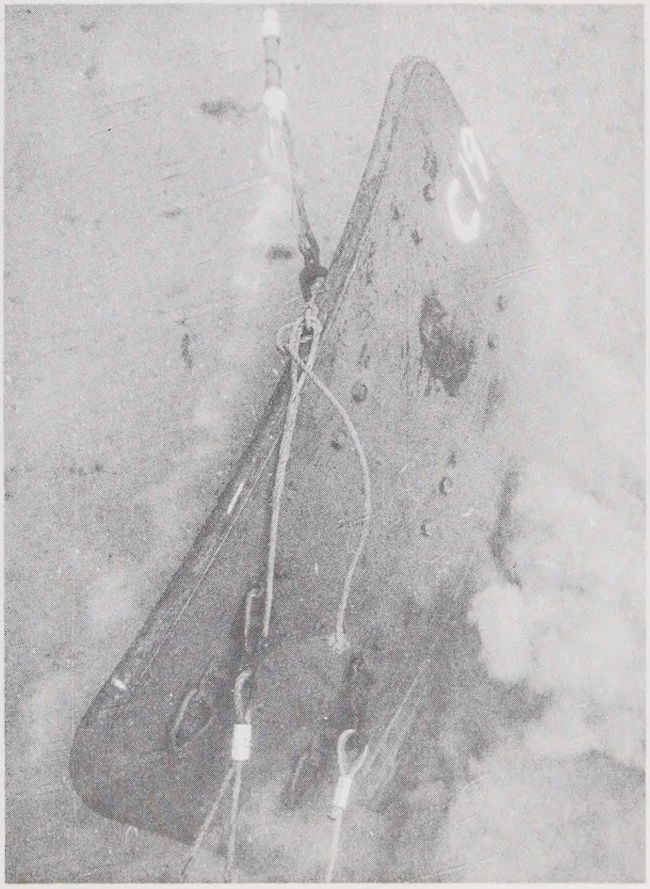

Plate IV. Fluorescein dye-pack attached to the warp in front of a steel cambered rectangular trawl board showing the direction of water flow past the board. Depth 25 m.

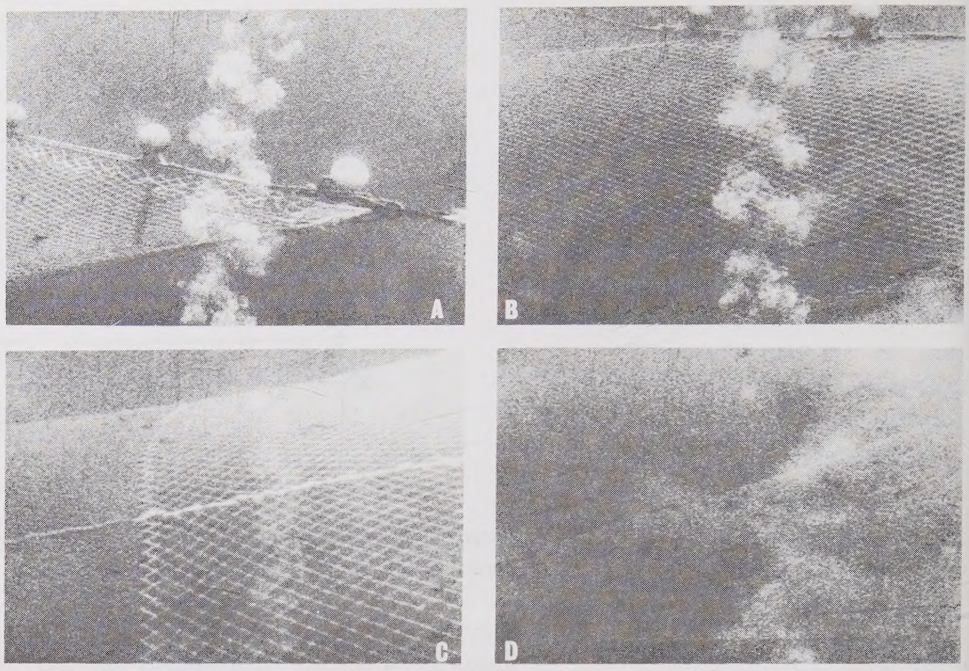

Plate V. Fluorescein dye experiment on a bottom trawl demonstrating the changes in the vertical dye column passing through the net (prints taken from 16 mm cine film). Depth 25 m.

Measurements, still and cine photography can pinpoint the areas of stress and slackness in commercial and experimental nets and the degree of contact with the sea bed. Plate VI shows the areas of tension and slackness on the top

Plate VI. Areas of tension and slackness around the headline of a Stella Granton Trawl. Depth 30 m.

section of a 29.3 m (96 ft) headline Stella Granton trawl towing at 3.5 knots (1.80 m sec^{-1}). Plate VII demonstrates the groundline rig of an experimental four panel trawl (a) in contact with, and (b) 'flying' off, the sea bed.

Plate VII (a). Groundline of an experimental four panel trawl in contact with the sea bed. Viewed near starboard side quarter. Depth 27 m.

Plate VII (b). The same net as in Plate VIIa, but owing to differences in rigging the net is not in contact with the sea bed. Depth 27 m.

The performance of otterboards in relation to speed and differing ground conditions were assessed by divers' observations and illustrated by photographic techniques, showing track angles in relation to sweep angles and the volume and spread of sand cloud disturbed by the boards. Plates VIII and IX demonstrate flat boards and cambered boards in action.

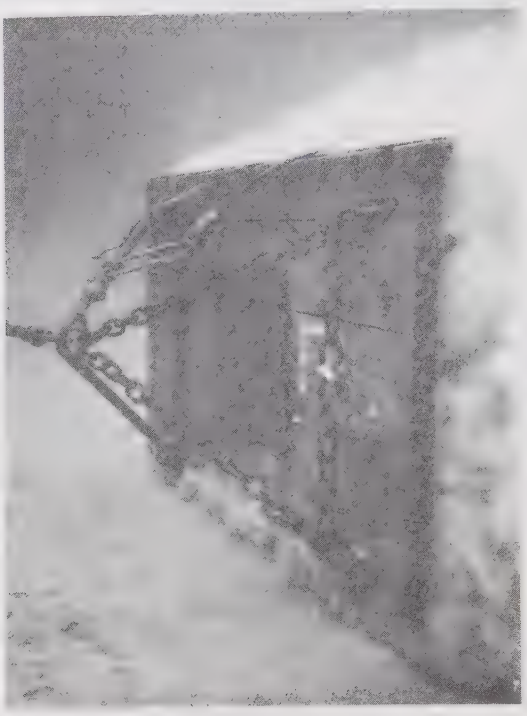

Plate VIII. Standard rectangular wooden trawl board: speed 3.2 knots (1.65 m s^{-1}), depth 25 m.

Plate IX. Vertical view of a steel cambered rectangular board on sandy bottom. Speed 3.5 knots (1.80 m s^{-1}), depth 25 m.

Discussion

Direct observation and quantitative measurements by divers on trawl fishing gear require the development of a great deal of personal skill and experience and have to be approached with caution. Initially, a great deal of time was needed to develop both the skill and the methods which would produce the maximum amount of relevant information during each dive in a limited 'no decompression' time. These new methods have resulted in a valuable set of data not obtainable by any other means.

Photography

When using still cameras in gear research, the problem was to record as much information on a 36 exposure film as possible. One must consider with what accuracy the pictures are to be analysed and what precise information is required. Usually it is not possible to obtain all the required information from a single print and it may be necessary to divide the filming work between two divers on any one dive, for example one filming from above and the other filming from the side of the gear.

Natural light photography is usually practicable in good conditions shallower than 30 m but is virtually impossible at depths much below 40 m in most northern waters. The use of artificial lighting was not considered to be beneficial or practicable, owing to the presence of suspended sediments disturbed by the gear, which cause severe scattering of light emitted from any light source (Hemmings, 1972).

Current problems and how they can be overcome

The main limits to current practice are (a) the limited diving time, (b) the faster towing speed of the fishing gears, and (c) water clarity and available light. Normally experiments were conducted between 25 and 35 m depth; diving at depths much greater than 40 m severely restricts diving time so that the amount of work produced will probably result in incomplete information. The number of measurements of spreads and heights using marked strings, for example, would often be insufficient in the time available to complete a set of results. To overcome this time problem, a new piece of apparatus has been developed - the diver-held acoustic rangefinder, which will measure the ranges faster and more accurately.

The towing speeds of commercial fishing boats may range from 3 to 4½ knots (1.54 to 2.32 m s^{-1}), depending on the type of gear in use and the grounds fished. At the moment, by modifications to breathing apparatus, it is possible to work on nets up to 3½ knots (1.80 m s^{-1}), but in excess of this speed the drag due to the water flow against the diver is too great to allow the collection of any accurate information. At speeds up to 4.5 knots (2.32 m s^{-1}), only 'pass' techniques are attempted, i.e. observations and photography of net behaviour as it passes the diver who remains to one side or above the gear. To overcome this problem, a newly developed towed wet submersible (Fig. 4) has been used to carry two divers with photographic and television equipment. This has allowed continuous observations of all parts of the trawl gear and boards at commercial towing speeds up to 5 knots (2.58 m s^{-1}). This system has its drawbacks, since the divers are still limited to the 'no decompression' time schedule. It may be found more advantageous, if fishing observations in deeper water are required, to develop the wet vehicle system without divers, and to operate the vehicle and camera by remote control.

The use of the vehicle carrying a diver operating the RCA Sitcon television camera has also overcome the problem of photography and water clarity. On occasions poor underwater visibility made conditions unsuitable for conventional cine and still shot filming, whereas results have shown that quality films of nets in action can be produced on video tape when visibility restricts a diver's vision to areas in his immediate surroundings. This method depends entirely on good communications between surface and diver.

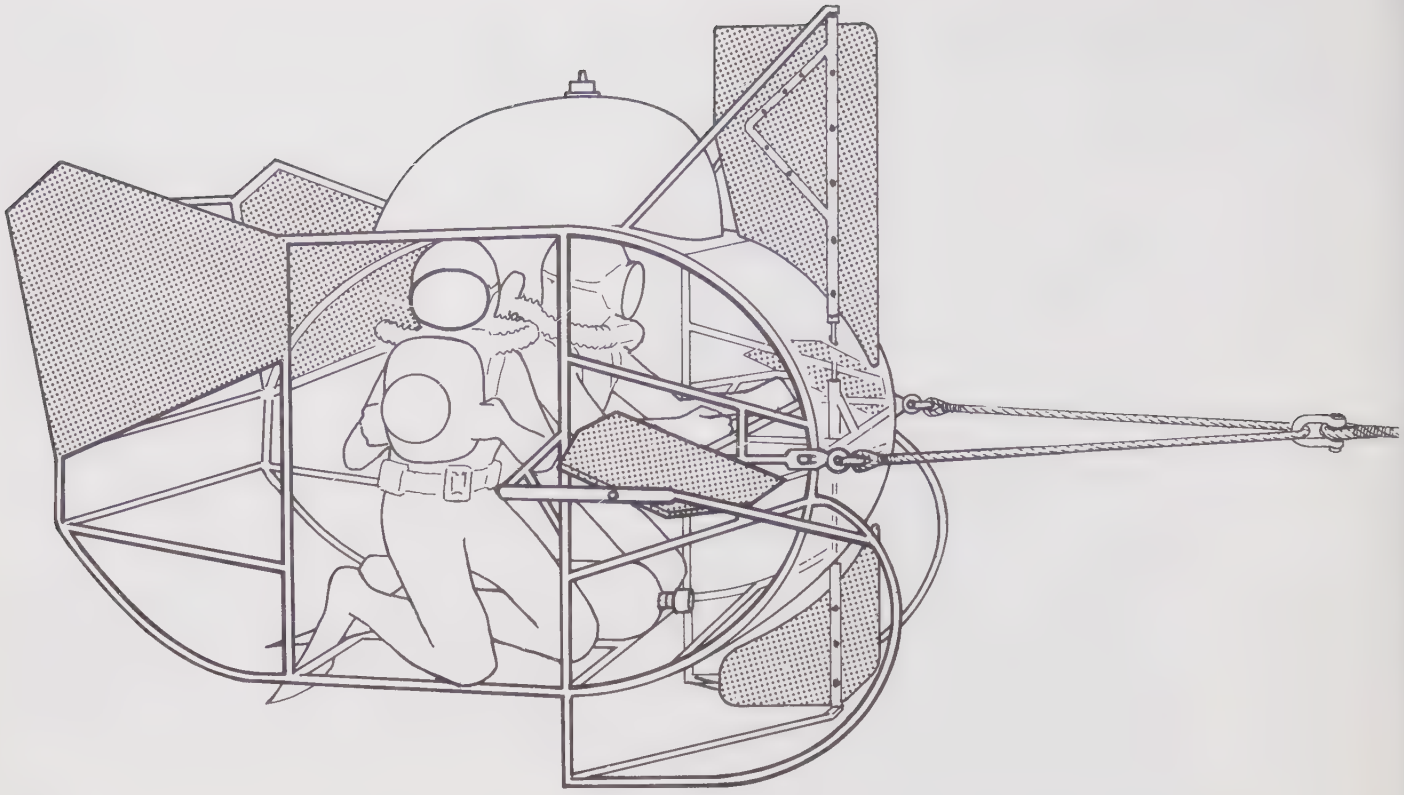

Figure 4. Two-man wet towed vehicle made from brazed tubular steel. The curved perspex screen shelters the divers. A fibreglass air chamber (top) with bleed valve and compressed air supply allows control of buoyancy. Two fins (laminated wood) control vertical and lateral movement of the vehicle.

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Summary Divers can measure and assess the critical factors influencing the geometry of fishing gears. The methods described involve the use of photography, linear measurement, depth gauges, low-light television, dye canisters and a towed wet submersible. These techniques have led to results not obtained by any other means. The advantages and disadvantages of the various methods are discussed together with their limitations.

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Appendix

Transcript of an actual commentary demonstrating the quantity of information a diver can produce in a relatively short dive.

J Main — 13 June Haul 1 Pass 1

Time 11.29 hrs — Divers JM and GIS

I am descending the starboard warp.
The water is quite clear today.
Kneeling on the sea bed awaiting the net - depth 29 m.
I can see the otterboard approaching - it is fishing OK and in contact with the sea bed along its base.
Very large sand cloud coming off the board.
I'm following the inside of the cloud trying to find the spreading wires.
Here are the wires, the lower one is hard on the sand and there is no twisting of the wires visible.
Sand cloud engulfing the wing end of the net.
Depth at wing end 27 m.
Pulling in the string for the spread measurement.
The wing end spread is 9.55 m.
Depth at starboard gusset 25.5 m.
I've now done the gusset spread which is 6.15 m.
I'm now at headline centre - depth 24.25 m.
Netting in the square region is very nearly perfect, no sign of strain or baggy patches at all.
Depth at starboard selvage front of square 25.75 m.
Spread across front of square 5.75 m.
Depth at starboard selvage back of square 26.25 m.
Spread across back of square 4.85 m.
Depth at back of square centre 24.75 m.
Depth at port selvage back of square 26.25 m.
Depth at port selvage front of square 25.75 m.
Depth at port gusset is 25.5 m.
Depth at port wing end is 27 m.
The groundline rig is in full contact with the sea bed, i.e. chain, rubber legs, and bobbins.
Letting go of the netting now and drifting back towards the codend - the net looks very good now.
Depth at join of both selvages near back of baitings 27.5 m.
Depth at the codend 27.5 m.
Spread through the codend (selvage to selvage) 0.45 m.
Depth on the sea bed 29 m.
Both divers now ascending to surface.
Time 11.37½ hrs.
Stop.

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